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The Albedo of Broken Cloud Fields: Calculations using a modified two stream radiation code

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Abstract

Cloud resolving models are a potentially useful tool for studying the cloud radiation interaction. However, such models still use plane parallel radiation transfer theory because more sophisticated methods require too much computer time. Results from Monte Carlo models show that the ratio of effective to geometric fractional cloud cover (N_e/N) is determined by the interception of direct solar radiation by the cloud sides, leakage of diffuse solar radiation through the cloud sides and cloud-cloud interactions. This note shows how the interception of direct solar radiation by the cloud sides can be included in a two stream radiation transfer code, suitable for use in cloud resolving models, which improves agreement with Monte Carlo models without requiring greater computing resources. Broken cloud fields are simulated and the ratio N_e/N calculated using the modified radiation code. At large solar zenith angles the interception of direct solar radiation by the cloud sides has the dominant effect on N_e/N and the calculated values are found to be in good quantitive agreement with the results of Kite (1987) who uses a Monte Carlo model.

1 Introduction

Numerous studies using general circulation models (GCM) show that clouds have an important effect on the Earth's radiation budget and climate. Because of the coarse spatial resolution of GCMs the cloud-radiation interaction is parameterized. This is done using plane parallel radiation transfer theory and assuming horizontally homogeneous clouds. However, both theoretical studies and observations show that the reflectivity of a finite

for use within cloud resolving models. The purpose of this note is to present a simple idea which allows some of the effects of cloud geometry to be reproduced by a modified two stream radiation transfer code, suitable for use in cloud resolving models. Use of this modified two stream code improves agreement with Monte Carlo models without requiring greater computing resources.

2 Two Stream Radiation Code

This section gives a brief description of the basic two stream equations for solar radiative transfer through a plane parallel multiple scattering (and absorbing) atmosphere. Although the material presented is standard, it is reproduced for clarity and to define the notation. Following on from this a modification to the two stream radiation code is proposed.

2.1 Standard two-stream equations

The basic two stream equations are

$$\frac{dF^+(\tau)}{d\tau} = c_1 F^+(\tau) - c_2 F^-(\tau) - \frac{c_3 F^0(\tau)}{\mu_0} \tag{2}$$

$$\frac{dF^-(\tau)}{d\tau} = c_2 F^+(\tau) - c_1 F^-(\tau) + \frac{c_4 F^0(\tau)}{\mu_0} \tag{3}$$

where τ is the optical depth, $F^+(\tau)$ and $F^-(\tau)$ are the upward and downward flux of diffuse radiation at a given τ, $F^0(\tau)$ is the direct solar flux and $\mu_0 = \cos\theta_0$ where θ_0 is the solar zenith angle. $F^0(\tau)$ is given by the simple Beer-Bouguer-Lambert law of extinction

$$F^0(\tau) = \mu_0 S_0 \exp^{-\tau/\mu_0}, \tag{4}$$

where S_0 is the local value of the solar constant.

The coefficients c_1, c_2, c_3, c_4 are given by the following equations:

$$\begin{aligned} c_1 &= D(1-\omega\alpha) \\ c_2 &= D\omega\beta \\ c_3 &= \omega\beta_0 \\ c_4 &= \omega(1-\beta_0) \end{aligned} \tag{5}$$

where D is the diffusivity factor, ω is the single scattering albedo, α and β are the fractional forward and backward scattering coefficients for diffuse radiation and β_0 is the

3 Numerical Results

The Edwards and Slingo two stream radiation code (Edwards and Slingo, 1994) is used to calculate the albedo of broken cloud fields. However, the radiation code is modified so that the calculation of the direct solar flux does not assume a plane-parallel atmosphere *ie* (8) is used instead of (4). From the calculated albedo the effective fractional cloud cover (N_e) of the broken cloud field is derived where N_e is defined as the fraction of a plane-parallel cloud layer required to give the same albedo as a broken cloud layer with the same optical properties.

Two-dimensional broken cloud fields are simulated as periodic arrays of rectangular clouds with homogeneous optical properties. Although these simulated cloud fields are not very realistic the intention is to compare our results with those from a Monte Carlo model (Kite, 1987) where a similar simplified form for broken cloud fields is used. The cloud optical properties are chosen to be similar to those used by Kite (1987). The clouds have a vertical depth of $2\,km$ with a vertical optical depth $\tau = 32$, an asymmetry factor $g = 0.85$ and a single scattering albedo $\omega = 1$ *ie* there is no absorption by cloud droplets. The cloud fields are represented on a grid with 40 levels with a vertical grid spacing of $50\,m$ and a horizontal spacing of $100\,m$. Because of this high spatial resolution the model can resolve the direct solar beam exiting one cloud and re-entering the next. For comparison purposes gaseous absorption is not included and the ground is non-reflecting.

Figure 1 shows numerical results calculated using the modified two stream radiation code. The ratio of effective fractional cloud cover to geometric fractional cloud cover (N_e/N) is shown as a function of geometric fractional cloud cover (N) for the simulated broken cloud fields (for plane parallel clouds $N_e/N = 1$). Computations are carried out for a solar zenith angle of 60° for clouds with aspect ratios of 2, 1 and 0.5 . N_e/N is found to be greater than unity because a large amount of the direct solar radiation is intercepted by the cloud sides. As might be expected high aspect ratio clouds have the highest ratio of N_e/N. Figure 1 can be compared with figure 2 which shows results from a Monte Carlo model (reproduced from figure 5a of Kite 1987) and shows good quantitative as well as qualitative agreement. Numerical results from the Monte Carlo model are in much better agreement with the modified two stream code than with the standard two stream code. However the modified two stream code over-estimates the ratio N_e/N by typically 20%. This is because the modified two stream code does not allow diffuse radiation to pass through the cloud sides. For a solar zenith angle of 0° Kite (1987) finds that the ratio N_e/N is less than unity, whereas our modified two stream code predicts $N_e/N = 1$. Again this is because the modified two stream code does not allow diffuse radiation to pass through the cloud sides.

4 Conclusion

This note has shown how the interception of direct solar radiation by the cloud sides can be included in a two-stream radiation code. Previous works, using Monte Carlo models, show that this is an important effect that can significantly enhance the cloud albedo. However, the method described here is no more computationally expensive than a standard two-stream radiation code and is much cheaper than Monte Carlo models.

Aircraft measurements described by Kite (1987) indicate that the effective fractional cloud cover (N_e) is a non-linear function of the geometric fractional cloud cover (N) and that an approximate relationship between them is given by $N_e = N^2$, which is very different from the results shown by both figures 1 and 2. As in Kite (1987), only the effect of cloud geometry has been examined by this note and cloud inhomogeneities have been ignored. Previous works show that both the cloud geometry and cloud inhomogeneities are important in determining the cloud-radiation interaction. Most works have concentrated on either the cloud geometry or the cloud inhomogeneities but have not studied both simultaneously and have thus failed to adequately explain observational results. It will be necessary to use more realistic simulations of broken cloud fields to understand the observational results. However, this is beyond the scope of this note and is left for future work.

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